CSC 249/449 Machine Vision: Midterm Exam
Term: Spring 2018
Instructor: Dr. Chenliang Xu
Date: March 20, 2018 12:30PM Eastern Time
Duration: 70 minutes; ends promptly at 1:40PM
Submission: hand **both** your solution and exam papers to the instructor or the TAs at the end of test session

Honor Code: By writing and submitting this exam, you are affirming that you have read and followed the University of Rochester Honor Code. You have also followed the constraints below.

Constraints:

1. This exam is intended to take up to 70 minutes. But, you may finish and submit it early.
2. This exam is independent and may not be discussed with other students.
3. This exam is closed-book, closed-notes, and closed-web.
4. This exam has no computer programming.
5. This exam is not to be distributed, posted or transferred.

Points: The exam totals 100 points with partial credit indicated per sub-problem.

Problem 1 (25): Short-Answer *(Expected Length: each answer should be 10 words or less and words 11+ will be disregarded. In fact, except the last question needs two words, there is one-word solution to first four questions, which is preferred. Expected Time: at most 2 minutes per question.)*

1. (5) How many degrees of freedom are there in a 2D homography transformation?
2. (5) What geometric property is preserved in a 2D affine transformation?
3. (5) Is human skin Lambertian?
4. (5) How many dimensions will the parameter space have in hough transform for circles?
5. (5) Name two Gestalt factors that lead to grouping.

Problem 2 (20): Image Features *(Expected Length: about 1 page. Expected Time: 15 minutes.)*

The Harris operator we discussed at length in lecture computes and analyzes the eigenvalues of the 2D gradient structure tensor (you have implemented this in Homework 1). Let λ_1 and λ_2 denote the larger and smaller eigenvalues, respectively. We select feature points based on the analysis of the eigenvalues (e.g., two small eigenvalues indicate a mostly absent gradient, one large and one small eigenvalue indicate an edge, and two large eigenvalues indicate a corner).

Now, consider a video parameterized over $(x, y, t) \in \mathbb{R}^3$. The eigenvalues of the 3D gradient structure tensor will similarly stratify the pixels in the video into different types. Let $\{\lambda_1, \lambda_2, \lambda_3\}$ denote the three eigenvalues of this 3D structure tensor (sorted in decreasing order).

Complete the following questions.

1. (10) First derive the form of the 3D structure tensor from the SSD error function (for window W):

   $$E(u, v, w) = \sum_{x,y,t \in W} [\mathbf{I}(x + u, y + v, t + w) - \mathbf{I}(x, y, t)]^2 \ .$$

   Then propose a criterion to extract "3D corners."
   Hints: recall that we used first-order Taylor approximation for small motions in the 2D case.

2. (10) Describe the different types of 3D structures by analyzing how the relation between the three eigenvalues can vary. And, answer the specific question: "What is a 3D corner?" Recall that you are answering these questions for the case of a video rather than a 3D image, such as an MRI scan. Although geometrically these may be the same, consider the special cases that will be observed by objects moving in video as your answer.

Problem 3 (35): Image Stitching *(Expected Length: 1-2 pages. Expected Time: 20 minutes.)*

Imagine the University of Rochester decided to have a floor-mural of "Meliora" painted on the Hajim quad. When the painting begins, you rush to the third floor of the Wegmans Hall so that you can look down and see it (a photo taken from the professor's office is shown on the right). On the first day you go up, the mural is about 25% done (they have finished the "Me") and take a photo. On the second day, they complete "lio", but you are not able to go up there to take a photo; your friend takes a photo with her camera but the image is very dark since she took it at dusk. On the third day, they finish, but when you get there a pile of snow is covering the "Me" so you cannot take a picture of the full mural.

1. You decided to stitch the three images together. First consider image 1 (from day 1) and image 3. You go through both images and identify a set of N matching features by hand. Let's assume you are working with a 2D affine transformation.

   (a) (10) Derive a least squares formula (you do not have to solve it, but need to explain the terms clearly) to estimate the parameters of the affine transformation that would align.

   (b) (2) What is the smallest N can be in order to solve it?

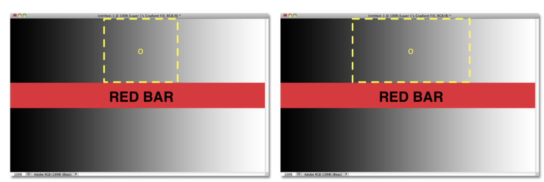
2. (10) Now, you consider stitching all three images but you are too lazy to manually find the correspondences. From those image features we discussed in class, identify one plausible set of image features to extract and match. Explain why you chose this type rather than another type.

3. Since it is winter in Rochester and we have a lot of snow. The snow will occlude part of the floor-mural and lead to spurious matches.

   (a) (10) Sketch an algorithm that will use the least squares method from part 1 and the features from part 2 to compute the transformation between images 1 and 3 for robust estimation.

   (b) (3) Can you guarantee with high probability (say up to 99%) chance that you will determine the correct transformation when the snow covers about half the area of the mural?

Problem 4 (20): Images as Graphs: Magic Wand *(Expected Length: about 1 page. Expected Time: 20 minutes.)*



The Photoshop Magic Wand tool requires **an image**, **a point click**, and **a threshold**; it will extract a segment consisting of pixels that are within certain distance in feature space from that clicked pixel. Here, we have a black-white gradient image with a red bar crossing the center horizon. We apply the Magic Wand tool on the same position (yellow circles denote the clicks) of the image under two threshold settings ($\tau_{left} < \tau_{right}$). The selected segments are shown as the yellow dashed regions; in both cases, they are **connected components** in an image graph. *(In graph theory, a connected component of an undirected graph is a subgraph in which any two vertices are connected to each other by some paths.)* Next, you will work through step-by-step to create such an algorithm behind the Magic Wand.

1. (5) Define a graph $\mathcal{G} = (V, E)$ for the image, i.e., explain the nodes and how nodes are connected by edges?
2. (15) Would Graph-Cut figure-ground segmentation be the best to implement the Magic Wand? If yes, please define clearly the energy functions and explain the terms. If not, please write down a plausible algorithm. (In either case, you should define the features, explain the color space and distance functions, and discuss how your algorithm is related to the user input threshold τ to achieve the results in the example.)